1 **The building blocks of a ‘Liveable Neighbourhood’: Identifying the key performance**
2 **indicators for walking of an operational planning policy in Perth, Western Australia**
3

4 **ABSTRACT**

5 Planning policy makers are requesting clearer guidance on the key design features required to
6 build neighbourhoods that promote active living. Using a backwards stepwise elimination
7 procedure (logistic regression with generalised estimating equations adjusting for demographic
8 characteristics, self-selection factors, stage of construction and scale of development) this study
9 identified specific design features ($n=16$) from an operational planning policy (“Liveable
10 Neighbourhoods”) that showed the strongest associations with walking behaviours (measured
11 using the Neighbourhood Physical Activity Questionnaire). The interacting effects of design
12 features on walking behaviours were also investigated. The urban design features identified were
13 grouped into the “*building blocks of a Liveable Neighbourhood*”, reflecting the scale, importance
14 and sequencing of the design and implementation phases required to create walkable, pedestrian
15 friendly developments.

16
17 **KEY WORDS**

18 Planning policy; liveable neighbourhoods; walking; health; built environment
19
20

21 INTRODUCTION

22 A vast body of evidence demonstrates associations between the built environment and levels of
23 walking and physical activity (Hooper et al., 2012; Saelens and Handy, 2008; Saelens and
24 Papadopoulos, 2008; Sallis et al., 2009; Transportation Research Board Institute of Medicine,
25 2005). Government policy and planning initiatives determine the way cities and towns are
26 developed and therefore play a vital role in shaping the neighbourhoods where residents can
27 safely and conveniently be physically active.

28
29 Despite a proliferation of evidence and increased attempts by active living researchers to promote
30 research findings to change urban planning policy and practice, there is a dearth of prescriptive
31 evidence about 'how much', of 'what types' of urban design features and infrastructure are needed
32 to support health and active living behaviours. Planning professionals and policy makers have
33 indicated that to help progress the influence of health research and its translation into planning
34 policy and practice there is an urgent need for practice-based evidence evaluating the
35 effectiveness of existing planning policies - using policy-relevant measures, (Allender et al., 2009;
36 Brownson et al., 2009; Durand et al., 2011; Koohsari et al., 2013). They also require clearer
37 guidance from active living researchers on the 'key' or 'essential' design features that promote
38 health outcomes and behaviours such as walking (Allender et al., 2009).

39
40 In 1998 the Western Australian State Government introduced the 'Liveable Neighbourhoods
41 Community Design Guidelines' (LN). A key intended outcome of the LN policy was to reduce
42 suburban sprawl and car dependence and encourage more walking, cycling and public transport
43 use. LN consists of four general design 'elements' (community design; movement networks; lot
44 layout; public parkland) that provide design guidance to assist in creating more compact, self-
45 sufficient, pedestrian-friendly neighbourhoods, with destination hubs (i.e., neighbourhood centres)
46 and public transport links. Each element contains a list of requirements of different design features
47 with a range of responses or criteria outlining how planners or developers could meet the element
48 objectives.

49

50 The introduction of LN provided a unique opportunity for a natural experiment. As such the
51 RESIDential Environments project (RESIDE) commenced with the aim of assessing the impact of
52 the new planning policy on local residents' walking and cycling behaviours and health outcomes
53 (Giles-Corti et al., 2008) and to provide longitudinal evidence to enhance the cross-sectional
54 evidence that dominates this literature. As part of the RESIDE project a process evaluation was
55 previously conducted to objectively measure the levels of on-ground policy implementation in in 36
56 housing developments across Perth using tailored spatial measures (Hooper et al., 2014). This
57 study revealed that the greater the implementation the better the walking outcomes. Indeed, there
58 was a dose-response relationship between overall levels of policy compliance and with each of its
59 elements (i.e., community design, movement network and lot layout) and walking behaviours
60 (Hooper et al., 2014).

61

62 The LN elements provide guidance on the built environment features considered to encapsulate
63 good 'New Urbanist' design (Duany et al., 2000) and stimulate walking. A simple scoring system
64 for quantifying levels of policy compliance was developed (Hooper et al., 2014). Additionally, a
65 cluster analysis identified the different mix of design features that had been implemented in the
66 developments and their associations with walking behaviour (Hooper et al., 2015). Both
67 approaches also helped to identify the number and range of policy requirements implemented and
68 the degree to which these had been implemented. However, these methods assumed that all of
69 the design features were of equal importance to walking outcomes - which may not be the case.

70

71 The LN policy is complex and contains a large number of different design features (up to 25 within
72 each of the four elements) for consideration. Western Australian planning policy-makers (including
73 the custodians of the policy – the Department of Planning) and practitioners (i.e., those
74 implementing the policy on-the-ground) have expressed interest in identifying whether any (and
75 which) of the design features are more effective than others in promoting walking.

76

77 In response to this demand and building on earlier work investigating the levels of LN compliance
78 and its associations with walking (Hooper et al., 2014), this paper sought to identify which of the

79 specific design features currently required under the policy are more, or less important in
80 encouraging walking. Using a backwards stepwise elimination procedure this paper considered all
81 of the design features within each of the four elements of the LN policy (i.e., community design,
82 movement network, lot layout and public parkland) to identify a hierarchy of 'key performance
83 indicators' of liveable suburban neighbourhood design that promote active living behaviours, such
84 as walking. The LN elements and their respective design features were not intended to be
85 implemented in isolation. It was therefore important to investigate combinations or interactions of
86 design features across the elements that were required to encourage walking behaviours, and to
87 represent these as 'building blocks' of a 'Liveable Neighbourhood", reflecting the sequencing
88 required in the design and implementation phases.

89

90 The two specific objectives of this paper were to: 1) identify the LN requirements from each
91 element that showed the strongest associations with walking behaviours; and 2) to investigate the
92 interacting effects of selected policy requirements on different walking behaviours.

93

94 **METHODS**

95 **Measuring implementation of policy requirements**

96 This paper follows the process evaluation that objectively measured the implementation of the
97 quantifiable requirements from the LN policy across its four elements for 36 new housing
98 developments being built in Perth, Western Australia (Hooper et al., 2014). Measures specific to
99 each of the LN policy requirements were developed and computed in a geographic information
100 system (GIS). Detailed information on the specific policy requirements and development of the
101 measures are reported elsewhere (Hooper et al., 2014). A brief description of the policy measures
102 included in this study is outlined in Table 1.

103

104 **Participants and self-reported walking behaviours**

105 The RESIDE study population comprised people who purchased land and were building new
106 homes in 73 greenfield developments across the metropolitan region of Perth, Western Australia.
107 Participants completed a self-report survey before they moved house (2003/04) and on three

subsequent occasions after relocating to their new suburban home (2004-2006). Full details of the RESIDE recruitment protocols and study design are available elsewhere (Giles-Corti et al., 2008).

110

The process evaluation focused on a subset of RESIDE participants (n=664) who were resident in 36 of the RESIDE developments (Hooper et al., 2014), had completed a RESIDE survey in 2009 and had lived in that development for at least two years. Walking behaviours were measured using the Neighbourhood Physical Activity Questionnaire (NPAQ), which has been shown to have acceptable reliability (Giles-Corti et al., 2006). Participants reported the frequency and duration of walking for transport (WT) and recreation (WR) within their neighbourhood in a usual week (Giles-Corti et al., 2006). Dichotomous variables (yes/no) were computed for >0 (any) and ≥60 mins/week of any WR and WT in the neighbourhood. Minutes of total walking (TW) were also dichotomised (yes/no) at >0 (any), ≥60 mins/week and ≥150 mins/week. This upper threshold of total walking was used to investigate whether participants were meeting recommended levels of physical activity through any type of walking.

122

123 **Identifying important LN requirements for walking**

All analyses were conducted in SPSS version 22. Logistic regression with generalised estimating equations (to control for clustering of participants within housing developments) was used to examine associations between the individual LN requirements and each of the walking outcomes. Variables (i.e. LN requirements) with potential associations (univariate p -value ≤ 0.1) were accepted into the next backwards elimination phase of analysis. This was run separately for requirements within each of the four elements to identify the specific requirements from each element that were associated with walking outcomes. At each stage of the backwards process the policy requirement with the highest p -value (and >0.05) was removed and the model re-fitted. This continued until all remaining LN requirements had p -values ≤ 0.05 which constituted the (final) multivariate model. All models adjusted for demographic characteristics (age; gender; education, children ≤ 18 years and under living at home) and neighbourhood-selection factors as well as the stage of construction and scale of development. The estimated odds ratios (and 95% confidence intervals) are presented for each requirement in the final multivariate models. The odds ratio

137 represents the relative increase in the odds of the walking outcome for that level of the requirement
138 in comparison to the reference level - yes/no for categorical requirements and for a one unit
139 increase in the level of the requirement for quantitatively measured requirements.

140

141 **Interaction effects of LN requirements and walking**

142 Interaction analyses assessed the interacting effect on walking of the movement network with the
143 provision of community infrastructure (in the form of neighbourhood centres and public open
144 space). All movement network requirements that remained in the final multivariate models (n=7),
145 plus the two MN requirements removed in the penultimate stage (the connected node ratio and cul-
146 de-sac street percentage) were examined with: 1) the community design requirement on the
147 presence and configuration of neighbourhood centres that remained in the final multivariate model:
148 and 2) the five public parkland requirements relating to the provision of and access to public open
149 space that remained in the final multivariate models. Each of the requirements entered into models
150 with interaction terms were first dichotomised (reflecting high vs. low levels of policy
151 implementation of that requirement). All models adjusted for demographic characteristics (age;
152 gender; education, children ≤ 18 years and under living at home) and neighbourhood-selection
153 factors as well as the stage of construction and scale of development.

154

155 **RESULTS**

156 The full demographic characteristics of the study population (n=664) are reported elsewhere
157 (Hooper et al., 2014). Briefly, the average age of participants was 43 years (SD 11.7), the majority
158 were female (62%) and married or in a de-facto relationship (87%) and about one-half of
159 participants had one or more children under the age of 18 years living at home.

160

161 Table 2 presents the estimated odds ratios (and 95% confidence intervals) results from the final
162 multivariate models containing the significant LN requirements from the community design (CD),
163 movement network (MN), lot layout (LL) and public parkland (PP) elements associated with each of
164 the walking outcomes. Table 3 presents the estimated odds ratios (and 95% confidence intervals)
165 results from the interactions analyses. Only those with significant associations are presented.

166

167 **INSERT TABLE 1 ABOUT HERE**

168

169 **Community design requirements and walking behaviour**

170 The configuration of the centre accessible within 1600m was associated with the odds of walking
171 within the neighbourhood: Compared with having no centre accessible within 1600m, having a 'big-
172 box' shopping centre was significantly associated with increased odds of undertaking ≥ 60 mins WT
173 (OR=1.7), as well as any TW (OR=3.1) and ≥ 60 mins of TW (OR=1.4) within the neighbourhood.
174 Having access to a main street configured centre was significantly associated with all walking
175 outcomes and a higher odds of walking compared with having access to a big-box centre.
176 Compared with having no accessible centre, the odds of doing any WT, WR and TW were more
177 than double for participants with access to a main street configured centre. The odds of doing
178 ≥ 60 mins TW per week increased by a factor of nearly seven (OR=6.7), and were substantially
179 higher for doing ≥ 60 mins WT (OR=1.7) and WR (OR=2.4). A greater diversity of destinations
180 provided within the centres was also associated with increased odds of doing any WT (OR=1.22
181 for every additional destination type), ≥ 60 mins WT (OR=1.36) and ≥ 150 mins TW (OR=1.16).

182

183 The presence of a primary school within 400m was, somewhat counter-intuitively, significantly
184 associated with lower odds of doing any WT (OR=0.55).

185

186 **Movement network requirements and walking behaviour**

187 Three MN requirements were positively and significantly associated with WT (Table 1): Each
188 additional external access point increased the odds of doing any WT by 35% (OR=1.35). For each
189 additional kilometre of footpaths in the development, the odds of doing any and ≥ 60 mins WT
190 increased by 2%; and for each additional tree provided along the footpath network the odds of
191 doing any WT increased by 4% (OR=1.04). Having a higher proportion of cul-de-sacs roads with
192 linking routes more than doubled the odds of doing ≥ 60 mins WT (OR=2.40).

194 Three MN requirements were significantly associated with WR (Table 1): Higher block densities
195 were associated with a nearly seven-fold increase in the odds of doing any WR (OR=6.83) and
196 five-fold increased odds of doing ≥ 60 mins WR (OR=5.14). Each extra kilometre of footpath
197 increased odds of doing ≥ 60 mins WR by 1% (OR=1.01). Notably, higher proportions of cul-de-
198 sacs with linking routes were associated with decreased odds of achieving ≥ 60 mins WR
199 (OR=0.64) (Table 2).

200

201 Four MN requirements were significantly associated with TW. Higher block densities were
202 associated with a five-fold increased odds of doing ≥ 60 mins TW (OR=5.05). A higher walkable
203 block ratio (i.e., numbers of blocks that met the policy requirement for size i.e., ≤ 620 m perimeter)
204 was associated with increased odds of undertaking any TW (OR=4.38, 3.24-5.91) and ≥ 150 mins
205 TW (OR=2.27) per week. For every one unit increase in the sidewalk:road ratio the odds of doing
206 ≥ 60 mins TW increased threefold (OR=3.14, 1.89-11.1) and for every one unit increase in the
207 density of trees positioned along the footpath networks the odds of doing ≥ 60 mins TW increased
208 by 2%.

209

210 **Lot layout requirements and walking behaviour**

211 The proportion of the residential land area occupied by small lots ($\leq 350\text{m}^2$) was the only significant
212 LL requirement. For every percentage increase in land area occupied by small lots the odds of
213 doing any WT increased by 4% (OR=1.04).

214

215 **Public Parkland requirements and walking behaviour**

216 Four PP requirements were significantly associated with doing any WT (Table 1). The odds
217 increased by 8% for every additional park (OR=1.08, 1.03-1.13), by 13% for every additional small
218 park (>0.3 to ≤ 0.5 ha), by 17% for each additional medium park (>0.5 to ≤ 1.5 ha) (OR=1.17, 1.06-
219 1.28) and increased four-fold with access to a regional park (>4 ha in size) within 2.5km (OR=3.97,
220 2.46-6.41). Access to a regional park was also significantly associated with doing ≥ 60 mins WT
221 (1.99, 1.83-2.17).

222

223 Just two PP requirements were significantly associated with the WR and TW outcomes (Table 1):
224 every additional medium-sized (>0.5 to ≤ 1.5 ha) park was associated with a 6-9% increased odds
225 of doing any and ≥ 60 mins WR and TW. Access to a regional park was associated with a 60-80%
226 increased odds of doing any and ≥ 60 mins WR and TW.

227

228 **Interacting effects of CD and MN requirements with walking behaviour**

229 Table 2 presents the estimated odds ratios (and 95% confidence intervals) of the interaction
230 analyses – many of which revealed that the effect of implementation of the MN requirements on
231 walking differed according to whether or not a neighbourhood centre was accessible within 1600m.
232 There were significant interactions between the presence and type of a neighbourhood centre and
233 street network connectivity with doing ≥ 60 min WR and TW, and ≥ 150 mins TW. Significant
234 interactions were also observed between the presence and type of a neighbourhood centre and
235 both cul-de-sac and sidewalk provision for ≥ 60 min of weekly WR and TW. There were no
236 significant interactions with WT as the outcome variable.

237

238 **INSERT TABLE 2 ABOUT HERE**

239

240 **Access to a neighbourhood centre and street connectivity**

241 Having access to a main street or big box centre had a major effect on walking (Table 2).
242 However, the association between connectivity of the street network, measured by the connected
243 node ratio, and the WR and TW outcomes was modified by the presence or absence of a centre
244 within 1600m (interaction terms $p < 0.001$). For people with no access to a centre within 1600m,
245 having a highly (versus low) connected street network had a large effect on the odds of doing
246 ≥ 60 mins WR (OR=9.96), ≥ 60 mins TW (OR=29.83) and ≥ 150 mins TW (OR=3.87) per week. For
247 people with access to a big-box configured centre, having high (versus low) street connectivity
248 increased the odds of achieving ≥ 60 mins WR by about 50% (OR=9.12/6.29 = 1.45), of achieving
249 ≥ 60 mins TW by 70% (OR=36.37/21.46 = 1.69) and achieving ≥ 150 mins TW by 60% (OR=5.07/3.23
250 = 1.57). Similarly, for participants with access to a main street centre, having a highly connected
251 street network provided 30% increased odds of achieving ≥ 60 mins WR (OR=20.42/15.94 = 1.28),

252 40% increased odds of achieving ≥ 60 mins TW ($OR=69.40/50.46 = 1.38$) and 30% increased odds
253 of achieving ≥ 150 mins TW ($OR=6.03/4.62 = 1.31$).

254

255 However, having access to a main-street configured centre within 1600m provided the most benefit
256 to increasing walking behaviour, regardless of the connectivity of the street network. The 'best
257 case scenario' for residents was living in developments with a main street centre and high street
258 connectivity. These residents had the highest odds of achieving walking; with a 20-fold increased
259 odds of doing ≥ 60 mins WR ($OR=20.42$), a 70-fold increased odds of doing ≥ 60 mins TW
260 ($OR=69.40$) and a six-fold increased odds of doing ≥ 150 mins TW ($OR=6.03$) compared with those
261 with no centre and low street connectivity (i.e., 'worst case scenario').

262

263 **Access to a centre and cul-de-sacs street percentage**

264 The association between cul-de-sacs street percentage with doing ≥ 60 mins WR and TW outcomes
265 was also modified by the presence or absence of a centre within 1600m (interaction terms
266 $p<0.002$) (Table 2). For people with no access to a centre, having low (versus high) cul-de-sacs
267 street percentages had a large effect on the odds of doing ≥ 60 min WR ($OR=9.18$) and ≥ 60 min TW
268 ($OR=29.27$) per week. For people with access to a big-box configured centre, having a low
269 (versus high) cul-de-sacs street percentage made little difference to the odds of doing ≥ 60 mins WR
270 ($OR=6.53/6.76 = 0.97$) or doing ≥ 60 mins TW ($OR=27.34/24.21 = 1.13$). For participants with access
271 to a main street centre, having a low (versus high) cul-de-sacs street percentages increased the
272 odds cul-de-sacs of doing ≥ 60 mins WR by 25% ($OR=18.56/14.85 = 1.25$) and increased the odds
273 of doing ≥ 60 mins TW by 36% ($OR=67.12/49.20 = 1.36$)

274

275 **Access to a centre and sidewalk provision**

276 The association of high (versus low) provision of sidewalks (i.e., the proportion of the road network
277 with footpaths adjacent to / running parallel to the road pavement) with the ≥ 60 mins WR and TW
278 outcomes was modified by the presence or absence of a centre within 1600m (interaction terms
279 $p<0.001$) (Table 2). For people with no access to a centre, high (versus low) provision of
280 sidewalks increased the odds of doing ≥ 60 mins WR three-fold ($OR=3.12$) and ≥ 60 mins TW six-fold

281 (OR=6.09). For people with access to a big-box configured centre, high (versus low) provision of
282 sidewalks made only a small difference to doing ≥ 60 mins WR (OR=2.94/2.25 = 1.31) and doing
283 ≥ 60 mins TW (OR=7.42/5.64 = 1.32). For people with access to a main street centre, having high
284 sidewalk provisions made a moderate difference to doing ≥ 60 mins TW (OR=12.04/7.16 = 1.68).
285 Participants with no centre but high provision of sidewalks had similar levels of WR and TW to
286 those with access to a big box centre (regardless of provision of sidewalks) whilst those with
287 access to a main street configured centre had the highest odds of walking.

288

289 **Interacting effects of PP and MN requirements with walking behaviour**

290 There were significant interactions between two PP requirements (the total number of parks and
291 the number of medium-sized parks) and the footpath:road ratio in their effects on achieving
292 ≥ 60 mins WR ($p=0.022$ and $p=0.023$, respectively). Compared with having low numbers of all
293 parks/medium-sized parks and low footpath provisions, participants living in housing developments
294 with higher total numbers of parks/ medium-sized parks and high levels of footpath provision had
295 an increased odds doing ≥ 60 mins WR (OR=2.47 and 2.47 respectively). Participants living in
296 housing developments with higher total numbers of parks/medium-sized parks or a high level of
297 footpath provision (but not both) did not have a significantly increased odds doing ≥ 60 mins WR.

298

299 There was also a significant interaction between the presence of a larger regional-sized park
300 (≥ 4 ha) and high levels of footpath infrastructure for ≥ 60 mins WT ($p=0.040$), ≥ 60 mins WR ($p=0.001$)
301 and ≥ 60 mins TW ($p<0.001$). Compared with participants with no access to a park ≥ 4 ha in size
302 within 2.5km and low footpath:road ratio, participants with access to a park ≥ 4 ha in size plus high
303 footpath:road ratios had significantly higher odds of achieving ≥ 60 mins WR (OR=2.04), ≥ 60 mins
304 WT (OR= 2.46) and ≥ 60 mins TW (OR=1.80). Additionally, access to a regional park, even with
305 low footpath provision was also associated with an increased odds of doing ≥ 60 mins WT
306 (OR=2.42) – and similar to that with high footpath provisions, suggesting that the provision of the
307 footpath network offered little increased benefit for achieving ≥ 60 mins WT when a regional-sized
308 park was accessible within 2.5km. Further, participants with no access to regional park but with
309 high provision of a footpath network had significantly lower odds of ≥ 60 mins WT (OR= 0.27),

310 ≥60mins WR (OR=0.35), and ≥60mins TW (OR=0.19) than participants with no access to regional
311 park and low provision of a footpath network.

312

313 **DISCUSSION**

314 A particular focus of the Western Australian 'Liveable Neighbourhoods' (LN) policy is to promote
315 walking (particularly transport walking). There has been much interest amongst local planning
316 policy makers and practitioners in the key components or policy requirements and design features
317 that promote walking. This study is unique in its attempts to provide practice-based evidence and
318 to begin to identify 'key performance indicators' representing a hierarchy of requirements for
319 encouraging or supporting residents' walking behaviours, from an operational planning policy in
320 Perth, Western Australia.

321

322 This paper builds on the previously reported process evaluation findings examining compliance
323 with the LN policy (Hooper et al., 2014) and different mixes or combinations of the design features
324 stipulated within the policy associated with different walking outcomes (Hooper et al., 2015). This
325 study has identified a smaller number (n=17) of specific policy requirements across the four
326 elements that (when implemented) accounted for the greatest association with walking outcomes.
327 The current findings also illustrates that the policy requirements interact with one another and thus
328 their implementation in isolation will likely not result in optimal conditions to support local walking.

329

330 These analyses have allowed the development of an empirically derived, refined list of the "key" LN
331 design features that showed the strongest associations with walking behaviour. These features
332 have been grouped into three 'building blocks of a liveable neighbourhood' (Figure 1). These
333 represent a hierarchy of design features related to: their scale (i.e., micro or macro); suggested
334 sequencing of the design and implementation phases in order to create walkable, compact,
335 pedestrian friendly developments; and their relationship with walking behaviour. All three blocks
336 are supported, by a consideration of density – whether that is the 'overall density' of the
337 development area, the 'targeted density' around centres and public transport hubs, and the 'design
338 and quality' of the density provided (Giles-Corti et al., 2012).

339
340 **INSERT FIGURE 1 ABOUT HERE**
341

342 **Building Block One: Structure and Connectedness**

343 This first building block represents the macro design features that create the foundation or
344 'footprint' of the development, setting out how it will be configured and connected for movement
345 within, throughout and across the development. The first building block facilitates walking within
346 the neighbourhood by determining the connectivity of the street networks, which in turn determines
347 the proximity to destinations. Both of these design features have consistently been associated with
348 walking behaviours (Oakes et al., 2007; Owen et al., 2007; Owen et al., 2004; Saelens et al.,
349 2003).

350
351 The importance of the movement network as the foundation building block is highlighted by this
352 study's interaction analyses which revealed that good street connectivity was significantly
353 associated with walking, even in the absence of a neighbourhood centre. This is also supported by
354 our previous work which indicated that compliance with the MN element was associated with the
355 greatest odds of WT in the neighbourhood (Hooper et al., 2014).

356
357 As an alternative measure of connectivity, and consistent with New Urbanist theory and the
358 requirements of LN, increased street block densities (reflective of smaller and a larger number of
359 blocks and more compact and denser developments) were associated with increased odds of both
360 recreational and total walking, although none of the transport-related walking outcomes. This latter
361 finding may be due to the generous provisions of LN allowing for block perimeters of up to 620m
362 (The Planning Group WA 2003). By international standards this block size is still large, and
363 suggests that the LN developments are meeting the letter but not spirit of this principle which aims
364 to reduce the size and increase the number of blocks to create more compact developments. A
365 large proportion of blocks at the upper limit of this threshold may reduce a development's
366 connectivity and overall neighbourhood density. However, Oakes et al (Oakes et al., 2007) also
367 found larger block sizes to be associated with increased odds of recreational walking. This may be

368 because the proximity of local destinations – particularly shops and services - is less important to
369 recreational walkers, provided the neighbourhood environment is pleasant (Sugiyama et al., 2012).

370

371 **Building Block Two: Activities and Mix**

372 The current results indicated that access to and diversity of destinations within community centres
373 and the provision of public open spaces were essential community design requirements for
374 encouraging both walking for transport and recreation behaviours in the neighbourhood. This
375 second building block therefore represents the installation of a mix of land uses and activities (i.e.,
376 other than residential) within the neighbourhood, providing public open spaces and places or
377 destinations for residents to visit and use. This building block provides residents with a 'reason' to
378 walk within their neighbourhood.

379

380 The importance of destinations for walking has been consistently observed in the literature (Cerin
381 et al., 2007; Cervero and Kockelman, 1997; Chanam and Moudon, 2006; Durand et al., 2011;
382 Transportation Research Board Institute of Medicine, 2005) and in other New Urbanist
383 neighbourhoods (Boer et al., 2007; Lund, 2003). Longitudinal evidence from the RESIDE project
384 further supports these cross-sectional findings providing evidence of a dose-response relationship
385 between transport walking and access to a mix of local neighbourhood destinations (Giles-Corti et
386 al., 2013; Knuiman et al., 2014).

387

388 Indeed, previous analyses that included all four of the LN policy elements in a multivariate model
389 highlighted that the community design element remained important for walking for transport
390 (Hooper et al. 2014). Furthermore, recent findings indicated that above and beyond the
391 implementation of the MN and LL requirements, the added combination of implementation of the
392 CD and PP requirements through the provision of neighbourhood centres and public open spaces
393 was associated with greater odds of walking for transport, recreation and meeting recommended
394 levels of physical activity through any walking (Hooper et al., 2015). Providing incentives that
395 facilitate the early installation and establishment of mixed-use centres or implementing business

396 development in specific areas to ensure residents have access to a mix of recreational and
397 utilitarian destinations to which to walk is therefore warranted.

398

399 McConville et al (McConville et al., 2011) have noted that previous measures and classification of
400 'retail' land uses incorporate shops in different configurations which may have widely varying
401 influences on pedestrian activity. A key principle of the CD element relates to the configuration of
402 the neighbourhood and town centres. Conventional big-box style centres tend to cater generously
403 for cars (Naess, 2005) and can be hostile, unwelcoming and unsafe environments for pedestrians.
404 The LN policy emphasises the installation of more traditional main-street mixed-use centres where
405 pedestrian-scaled, street-fronting retail layouts that encourage walking and cycling access
406 predominate. This study revealed that in addition to having destinations to walk to, the
407 configuration of the centre in which these are located is highly important for encouraging walking
408 behaviour. Whilst having a big box configured centre provided some benefit in terms of increasing
409 walking, the provision of the main-street centres was associated with greater odds of doing any TW
410 and ≥ 60 mins per week of transport, recreational or any walking within the neighbourhood.

411

412 This supports previous findings by Cervero and Kockelman (Cervero and Kockelman, 1997) who
413 found that neighbourhoods with more on-street parking in commercial areas, and thus a greater
414 pedestrian emphasis, had fewer single-occupant car travel for non-work purposes. Similarly, Pikora
415 et al (Pikora et al., 2006) found that respondents living in neighbourhoods with more off-street,
416 large car parking facilities at destinations had lower odds of walking for transport. A recent 'Good
417 for Business' report by the Australian Heart Foundation (Tolley, 2011) also concluded that creating
418 town centres in more attractive, pedestrian orientated main-street formats significantly increases
419 pedestrian activity and is important in helping to create a modal shift from the car to walking trips.

420

421 The association of WR with the main street configured centres may be explained by Handy
422 (Handy, 1996). She suggests that whilst the primary motive for recreational walking is the act of
423 walking itself (i.e., for pleasure or exercise), individuals may still set out with a particular destination
424 in mind. Additionally, work by Moudon and colleagues (Moudon et al., 2006) suggests that whilst

425 destinations such as supermarkets are usually associated with necessary spending and utilitarian
426 trip purposes, the presence of a diverse mix of destinations associated with discretionary spending
427 (such as cafes, restaurants and retail) and community or civic uses and spaces, located in
428 pedestrian-orientated main street centres, may provide both destinations and an interesting route
429 for recreational walking (Sugiyama et al., 2012)

430

431 This study also revealed the important interactions between the 'structure and connectedness' and
432 'activities and mix' building blocks and the need to align them for optimal walking outcomes. The
433 interaction results revealed that having access to a main-street configured centre within 1600m
434 provided the most benefit to increasing walking behaviour, regardless of the connectivity of the
435 street network. Conversely, over and above a highly connected street network, the provision of a
436 'big-box' configured centre provided little or no additional benefit in terms of encouraging walking.
437 However, the provision of a main street centre in combination with a connected underpinning street
438 network provided the optimal conditions for encouraging walking behaviour.

439

440 Parks and areas of public open space provide another form of destination for residents to walk to
441 and within (Sallis et al., 2009; Sugiyama et al., 2010; Ulrich and Addoms, 1981). Indeed, the
442 provision of more parks throughout the neighbourhood was associated with increased odds of
443 doing any transport walking and any and ≥ 60 mins per week of recreational and total walking.
444 However, the presence of a larger 'destination' (regional) park was associated with greater odds of
445 doing both any and ≥ 60 mins per week of transport, recreational and total walking. Longitudinal
446 results from RESIDE also showed for each type of recreational destination (i.e., park, playing field
447 or beach) gained after relocation participants recreational-walking increased by around 18
448 minutes/week (Giles-Corti et al., 2013). Parks also facilitate social interactions and play a role in
449 increasing social capital by providing places where people to gather and develop social ties
450 (Bedimo-Rung et al., 2005; Kuo et al., 1998) (Chiesura, 2004; Wolch et al., 2014) and another
451 intended objective of the LN policy

452

453

454 The interaction results also revealed that where there were a high number of parks with footpaths,
455 people were almost 2.5 times to walk achieve ≥ 60 mins walking for recreation each week.
456 However, participants with access to a larger (regional) park were more likely to undertake ≥ 60
457 mins transport, recreation or total walking irrespective of the footpath provisions. When no large
458 park was accessible, participants were less likely to walk even with good footpath provisions.
459 These findings are consistent with other elsewhere that has found access to larger, more attractive
460 parks to be associated with walking for recreation (Giles-Corti et al., 2005; Sugiyama et al., 2010).

461

462 After controlling for the presence of children living at home and the provision of a neighbourhood
463 centre, the presence of a primary school within 1600m was negatively associated with walking for
464 transport. This was contrary to expectations, however consistent with other findings suggesting
465 that large land parcels allocated for school sites and offices were “deterrent” land uses and
466 negatively associated with walking in adults (Moudon et al., 2006). Indeed, the LN policy
467 recognises that *“the trend towards larger primary schools and their large site area (some 4 ha) may*
468 *interfere with walkability and a reduction in the potential catchment of the neighbourhood centre”*
469 (Western Australian Planning Commission 2000), pg.15). This is important, given
470 recommendations to co-locate schools with town centres, which may decrease the potential for
471 adults to walk to the town centre, and children to walk to school (Giles-Corti et al., 2011).

472

473 Nevertheless, 11 of the 13 regional-scaled developments in this study of sufficient size to require
474 the provision of a primary school, did so. Schools were constructed early in the development
475 phase, perhaps to encourage young families to buy into the development. However, only seven of
476 these developments had installed a neighbourhood centre at the time of evaluation. Thus it is
477 possible that it was not the presence of the school *per se* that discouraged walking for transport but
478 rather the absence of utilitarian destinations. Whilst the provision of school sites is an important
479 community destination, particularly for increasing the likelihood of children using active modes to
480 school, reliance on a primary school alone to generate walking trips is insufficient as an attractor or
481 anchor destination for creating walkable neighbourhoods. The presence of a primary school is
482 only likely to be a destination for primary aged children and their parents, not for other adult

483 residents. Moreover, the trend towards larger primary schools may deter children from walking
484 and cycling to school and encourage parents to chauffeur their children by car (Trapp et al., 2013).

485

486 **Building Block Three: Design Details and Quality**

487 The third 'building block' relates to the detail and quality of the neighbourhood design and micro
488 features that enhance the walking experience and make walking within the neighbourhood an
489 attractive, safe and desirable option. Quality design contributes to creating walkable and enjoyable
490 places, buildings, streets, and parks. This includes the provision of footpaths along the connected
491 street networks (providing a safe alternative to driving) and trees to provide shade from the hot
492 climatic conditions of WA (Cervero and Kockelman, 1997) and a buffer between the sidewalk and
493 traffic – creating a safer walking environment (Burden, 2006; City of Melbourne, 2011), as well as
494 the building design and frontage to streets and the road design (widths and intersections) to create
495 slower vehicular movements.

496

497 This study highlight the importance of footpaths for walking and are consistent with those found
498 elsewhere (Duncan and Mummery, 2005; Hess et al., 1999; Pikora et al., 2006; Saelens et al.,
499 2003). Two footpath variables remained in the multivariate models with full adjustment. The first
500 (total footpath length) reflected the total footpath provisions throughout the development. This
501 included all footpaths that were positioned alongside roads (i.e., sidewalks) as well as those
502 through parks and areas of open space and pedestrian access-ways or laneways linking cul-de-
503 sac terminations or road reserves, reflecting a higher connectivity of routes for pedestrians.

504

505 The importance of pedestrian infrastructure alongside the road network (i.e. sidewalks) was also
506 important, as called for in the LN policy, as it positively moderated interactions with the access to
507 neighbourhood centres for recreational and total walking – again highlighting the need to align and
508 install in combination design features from the different building blocks

509

510

511

512 **Supporting Block: Density**

513 An important supporting characteristic for each block in the hierarchy, and an essential
514 consideration at each stage of the design process is residential density. Alone, there have been
515 mixed results and relatively weak relationships between residential density and walking. Density
516 by itself does not increase walking and cycling for transport. However, higher densities tend to
517 result in the creation of more compact development thereby decreasing the distances between
518 housing and destinations. The 'overall density' of a development is thus an important consideration
519 when designing its 'footprint' or structure and connectedness. The level of density influences the
520 provision of local destinations and public transport services that encourage active modes of travel
521 making them both viable and accessible (Ewing and Cervero, 2010; Handy and Clifton, 2001;
522 Transportation Research Board Institute of Medicine, 2005). Consideration of higher density
523 development 'targeted' around community centres and public transport hubs is thus an important
524 consideration to support provision of a mix of land uses and activities. Finally, the 'design and
525 quality' of higher density development is another important consideration. This will ensure the
526 quality of the design of 'liveable' higher density residential dwellings (Giles-Corti et al., 2012; Udell
527 et al., 2014). It includes consideration of its appearance and amenity, form, size or scale, and
528 relationship with the streetscape

529

530 **Strengths and Limitations**

531 A limitation of this study is the relatively small sample size of residents, which most likely accounts
532 for the large confidence intervals for the interaction results. The lack of significant associations
533 with walking for transport in the interaction analyses is likely to be a result of the relatively small
534 number of participants who reported using active modes of transport to and from their place of
535 work. However, the use of precise, policy-specific GIS measures of the new developments on
536 greenfield sites is a particular strength. The results are directly applicable to suburban areas
537 throughout Australia and the United States (US), that have typically followed conventional design
538 principles, as well as European settings as new towns are developed on greenfield sites. A
539 strength of this study was the inclusion of self-selection factors in models. Notably, the
540 associations observed persisted after controlling for self-selection, measured as participants'

541 preferences for particular neighbourhood features. This suggests that regardless of residents'
542 preferences for 'walkable' or 'liveable' features, implementation of the 16 policy requirements
543 encouraged walking within the neighbourhood. This finding is consistent the longitudinal results
544 from RESIDE (Giles-Corti et al., 2013; Knuiman et al., 2014) and suggest that creating more
545 walkable neighbourhoods would increase local walking, even in those who chose their
546 neighbourhood for reasons other than its walkability.

547

548 **CONCLUSION**

549 This study aimed to identify a shortlist of policy requirements from an operational state planning
550 policy that showed the strongest associations with walking behaviours in order to begin to identify a
551 hierarchy of design features that are important for encouraging or supporting residents' walking
552 behaviours. Sixteen policy requirements were identified across the four elements and grouped
553 under three different "*building blocks of a liveable neighbourhood*" supported by appropriate
554 densities, to represent a hierarchy of requirements related to their scale (i.e., micro or macro), and
555 suggested ordering of consideration in the design and implementation phases in order to create
556 walkable, compact, pedestrian friendly developments and neighbourhoods.

557

558 The impact of micro-design elements such as street trees and landscaping (i.e., the detail and
559 desirable features) although more easily implemented, is likely to be too small on their own to exert
560 any fundamental influences on travel and recreational behaviour in a low density, homogenous
561 residential neighbourhood. In contrast, the implementation of macro urban planning features such
562 as street connectivity with sufficient residential densities provide the foundation of walkable
563 communities and result in more compact neighbourhoods that support the provision of
564 neighbourhood centres and quality public open spaces. Together these are the principal
565 underlying determinants of walking within the neighbourhood, and the most difficult to retrofit.
566 Implementation of these macro features should therefore be the first to be considered, incentivised
567 and enforced in the design and development processes of new suburban neighbourhoods, to
568 which other micro features can be added. The interaction analyses has also highlighted that each

569 block of design features is essential in its own right, but to bring about optimal walking outcomes
570 these need to be aligned vertically and implemented in combination.

571

572 Evidence-based planning requires information on thresholds relating the design features (e.g., the
573 optimal distance to a neighbourhood centre or the mix of destinations within it to promote walking
574 or the level of density for positive health outcomes) to incorporate into planning guidelines or
575 policies. There is also a lack of studies examining the cost-effectiveness of creating more walkable
576 and liveable neighbourhoods or planning policies. Further research in these is required to advance
577 evidence-based planning.

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Table 1 Objective measures of the community design, movement network, lot layout and public parkland requirements from the Liveable Neighbourhoods policy that were entered into the multivariate analyses*

COMMUNITY DESIGN	
Access to Neighbourhood Centres	
<ul style="list-style-type: none"> Distance to the nearest neighbourhood/town centre¹ Centre accessible within 400m (Yes/No)² Centre accessible within 800m (Yes/No)² Centre accessible within 1600m (Yes/No)² 	
Configuration of Neighbourhood centre accessible within 1600m	
<ul style="list-style-type: none"> Main street layout Big-box layout 	
Diversity of Destinations within Neighbourhood Centres	
<ul style="list-style-type: none"> Destination diversity score - number of different destination types present within the centre (score 1-8): <ol style="list-style-type: none"> Number of convenience goods stores: <i>Supermarkets; deli's; speciality food stores(i.e., butchers, greengrocers, fishmongers); liquor stores and bottle shops; newsagents and confectionary retailers; service station shops</i> Number of retail goods stores: <i>Fashion and apparel stores, footwear and accessories shops; jewellery stores; books, games, music, DVD/video stores; cards, souvenirs and gift stores; personal electronic and telecommunications; variety and discount stores</i> Number of general services: <i>Hair and beauty; banks and finance; personal health (e.g., pharmacies); video/DVD rental; laundry and tailoring</i> Number of medical and health care services: <i>Medical centres; other medical and health services (e.g., dentist, physiotherapist);</i> Number of places of worship: <i>Churches, mosques, temples and synagogues</i> Number of community services and facilities: <i>Community centres; day care centres / crèches; libraries</i> Number of eating and drinking out establishments: <i>Restaurants, bars, fast food outlets, hotels, taverns, pubs, bars, nightclubs</i> Number of entertainment and amusement places: <i>Cinemas; theatres; concert halls; museums, art galleries; gaming and gambling venues; sporting (spectator) venues</i> 	
Access to Public Transport	
<ul style="list-style-type: none"> Distance to the nearest bus stop¹ Bus stop accessible within 400m (Yes/No)² Number of bus routes through the development Number of bus services to/from the development Distance to the nearest train station¹ Train station accessible within 800m (Yes/No)² 	
Access to Primary Schools	
<ul style="list-style-type: none"> Distance to the nearest primary school¹ Primary school accessible within 1600m (Yes/No)² 	
MOVEMENT NETWORK	
Connectivity of the Street Networks	
<ul style="list-style-type: none"> Connected node ratio (number of 3 + 4 way intersections ÷ total number of all intersections including cul-de-sacs) Mean block perimeter Block density = number of blocks ÷ constructed land area within the development Walkable block ratio = number of blocks ≤620m perimeter ÷ total number of blocks 	
External Connectivity	
<ul style="list-style-type: none"> Number of external access points = number of pedestrian-friendly access points along the development perimeter ÷ perimeter of development boundary (km) 	
Cul-de-sac provision and design	
<ul style="list-style-type: none"> Cul-de-sac length ratio = number of cul-de-sacs ≤120m in length ÷ total number of cul-de-sacs Cul-de-sac link ratio = number of cul-de-sacs with a pedestrian cut through ÷ total number of cul-de-sacs Cul-de-sac lot ratio = number of cul-de-sacs serving ≤20 residential lots ÷ total number of cul-de-sacs Percentage of residential lots on cul-de-sacs (≤ / > 15%) = number of residential lots served by a cul-de-sacs ÷ total number of residential lots) Cul-de-sac street % = length of all road network segments terminating in a cul-de-sac ÷ total length of all road centrelines 	
Total footpath provision	
<ul style="list-style-type: none"> Footpath length per unit area (ha) = length of all footpaths ÷ constructed land area of housing development Footpath to road ratio = length of all footpaths within the development ÷ length of all roads within the development 	
Footpaths on both sides of the street?	
<ul style="list-style-type: none"> % of road length with sidewalks (i.e., footpath segments that ran alongside the road) Sidewalk to road ratio = length of all footpath segments alongside/adjacent to roads ÷ length of all roads 	

Streetscapes – Trees along footpaths

- Tree density along footpaths = number of trees along footpaths (within a 5m buffer) ÷ length (km) of footpaths within the development
- Tree canopy cover = area of footpath shaded by tree canopy cover ÷ total footpath area within the development

LOT LAYOUT

Residential lot size

- Mean residential lot size
- Median residential lot size
- Number of different lot sizes present (categories: $\leq 350\text{m}^2$; $>350 - \leq 550\text{m}^2$; $>550 - \leq 750\text{m}^2$; $>750 - \leq 950\text{m}^2$; $>950\text{m}^2$)
- Residential land areas occupied by different lot sizes
- % of lots $\leq 350\text{m}^2$ (i.e., “small” lots for medium density housing)

Housing diversity development-wide

- Number of dwellings by type (n=9) as a % of the total number of dwellings
- Residential land area occupied by different (n=9) dwelling types = the total number of different dwelling types present within each development (score = 1-9):
1) Single detached houses; 2) Semi-detached houses; 3) Duplex unit; 4) Triplex unit; 5) Town house; 6) Terrace house; 7) Group house; 8) Villa house; and 9) Flat or apartment. Housing types 3-8 (inclusive) represent medium density housing models.

PUBLIC PARKLAND

Amount and type of parks

- Area (ha) of all parks + publicly accessible school grounds
- % provision of parks = area of all parks + publicly accessible school grounds ÷ gross constructed land area of housing development ($< / \geq 10\%$)
- Total number of parks within the development
- Number of local parks
- Number of neighbourhood parks
- Number of district parks
- Number of regional parks ($>4\text{ha}$)

Access to parks

- Any park accessible within 400m (Yes/No)
- Local park ($\leq 0.3\text{ha}$) accessible within 200m (Yes/No)
- Small neighbourhood park ($0.3-0.5\text{ha}$) accessible within 400m (Yes/No)
- Medium neighbourhood park ($0.5-1.5\text{ha}$) accessible within 400m (Yes/No)
- Large neighbourhood park ($1.5-2.5\text{ha}$) accessible within 400m (Yes/No)
- District park ($2.5-4\text{ha}$) accessible within 600m-1km (Yes/No)
- Regional park ($\geq 4\text{ha}$) accessible within 2.5km (Yes/No)

Park surveillance and safety

- Park perimeter frontage ratio = % of the park perimeter bordered by lots facing the park
- Park perimeter roads ratio = % of the park perimeter bordered by adjacent roads

¹ Distance computed along the road network from all residential dwelling points (n=31,102) to the nearest centre, bus stop, train station, primary school and parks. For each development the mean distance to each of these destinations was computed.

² Deemed accessible if $\geq 10\%$ of the dwellings within a development had access to a centre within the specified distance

* *This is an abridged version of a Table previously published by the authors (Hooper et al., 2014)*

Table 2 Odds ratios (OR) of LN requirements significantly associated with walking outcomes in the multivariate models (n=664)[†]

Liveable Neighbourhoods Policy Requirement		Walking for transport		Walking for recreation		Total walking		
		Any	≥60 mins	Any	≥60 mins	Any	≥60 mins	≥150 mins
Community Design								
	None	1.00	1.00	1.00	1.00	1.00	1.00	
Configuration of neighbourhood centre ≤1600m*	Big Box	1.38 (0.82-2.31)	1.68 (1.20-2.36)	1.07 (0.77-1.50)	0.95 (0.71-1.26)	3.10 (2.32-4.15)	1.44 (1.10-2.06)	
	Main St	2.10 (1.38- 3.16)	1.70 (1.05-2.68)	2.28 (1.53-3.38)	2.37 (1.74-3.23)	5.51 (4.32-7.02)	6.65 (4.63-9.54)	
Destination diversity of centre [OR for every additional destination type present]		1.22 (1.01-1.49)	1.36 (1.11-1.68)					1.16 (1.05-1.27)
Primary School ≤400m [OR vs. reference group no school ≤400m]		0.55 (0.35-0.86)						0.18 (0.09-0.33)
Movement Network								
Block density* [OR for 1 unit increases in block density = no. of blocks per ha]				6.83 (3.6-13.1)	5.14 (1.99-13.2)		5.05 (2.10-12.1)	
Walkable block ratio* [OR for 1 unit increases in walkable block density]						4.38 (3.24-5.91)		2.27 (1.40-3.68)
Cul-de-sacs Link Ratio ≥50%* [OR vs. reference group <50% cul-de-sacs Link Ratio]			2.40 (1.09-5.26)		0.64 (0.47-0.86)			3.24 (1.43-7.36)
Number of external access points* [OR for 1 unit increase in number of access points]	1.35 (1.06 -1.73)							
Length of footpaths (km) * [OR for 1 unit increase in length of footpaths]	1.02 (1.01 - 1.02)		1.02 (1.00-1.03)		1.01 (1.00-1.02)			
Sidewalk : road ratio* [OR for 1 unit increase in sidewalk: road ratio]							3.14 (1.89-11.1)	
Tree density along footpaths* [OR for 1 unit increase in number of trees per km of footpath]	1.04 (1.03-1.06)						1.02 (1.01-1.04)	
Lot Layout								
% residential land area occupied by small lots (≤350m ²) [OR for 1 unit increase in % residential land area]	1.04 (1.01-1.09)							
Public Parkland								
Medium neighbourhood park (>0.5 to ≤1.5ha) ≤400m* [OR Yes vs. reference group no park ≤400m]		1.09 (1.05-1.12)						
Number of parks* [OR for 1 unit increase in number of parks present within the development]	1.08 (1.03-1.13)							
Regional park (≥4ha) ≤2.5km* [OR Yes vs. reference group no regional park ≤2.5km]	3.97 (2.46-6.41)	1.99 (1.83-2.17)		1.63 (1.40-1.91)	1.82 (1.20-2.75)	1.58 (1.35-1.84)	1.85 (1.23-2.50)	
Number of small neighbourhood parks (>0.3 to ≤0.5ha) * [OR for 1 unit increase in number of parks present within the development]	1.13 (1.02-1.25)							
Number of medium neighbourhood parks (>0.5 to ≤1.5ha) * [OR for 1 unit increase in number of parks present within the development]	1.17 (1.06-1.28)			1.09 (1.06-1.13)	1.08 (1.03-1.11)	1.06 (1.02-1.10)	1.09 (1.04-1.13)	
Number of parks with sports surfaces, marking or equipment [OR for 1 unit increase in number of parks present]		1.26 (1.18-1.34)						

* Policy requirements that were included in the interaction analyses

738 **Table 3** Results of multivariate models[†] showing adjusted interactions between requirements of the community design, movement
739 network and lot layout elements and associations with doing ≥60 minutes of total, transport and recreation walking within the
740 neighbourhood in a usual week and meeting recommended levels of total walking (≥150 minutes) in a usual week

Liveable Neighbourhoods Requirements	≥ 60 minutes of walking for transport per week			≥ 60 minutes of walking for recreation per week			≥ 60 minutes of total walking per week			≥ 150 minutes of total walking per week		
	OR	95% CI	p value	OR	95% CI	p value	OR	95% CI	p value	OR	95% CI	p value
Configuration of neighbourhood centre within 1600m × movement network requirements												
Configuration of centre 1600m (main street/big box) × connected node ratio (high/low)												
Overall Interaction Term			0.677			0.000			0.000			0.000
No centre × connected node ratio (Low) *	1.00			1.00			1.00			1.00		
No centre × Connect. Node Ratio (High)	1.98	0.65-6.04	0.232	9.96	2.83-35.07	0.000	29.83	5.65-157.65	0.000	3.87	1.34-11.15	0.012
Big Box (Yes) × Connect. Node Ratio (Low) ¹	5.77	2.49-13.37	0.000	6.29	1.86-21.33	0.003	21.46	4.16-110.86	0.000	3.23	1.22-8.59	0.019
Big Box (Yes) × Connect. Node Ratio (High)	6.49	1.87-22.53	0.003	9.12	2.67-31.21	0.003	36.37	6.95-190.43	0.000	5.07	1.85-13.90	0.002
Main St. (Yes) × Connect. Node Ratio (Low)	7.73	3.33-17.95	0.000	15.94	4.71-53.95	0.000	50.46	9.87-257.98	0.000	4.62	1.76-12.18	0.002
Main St. (Yes) × Connect. Node Ratio (High)	9.59	4.21-21.82	0.000	20.42	5.89-70.77	0.000	69.40	13.33-361.42	0.000	6.03	2.18-16.65	0.001
Configuration Of Centre 1600m (No centre/Main Street/Big Box) × Cul-De-Sac Street Percentage (High/Low)												
Overall Interaction Term			0.551			0.002			0.000			0.074
No centre × High cul-de-sacs st. % (Bad) *				1.00			1.00			1.00		
No centre × Low cul-de-sacs st. % (Good)	2.14	0.71-6.43	0.174	9.18	2.43-34.77	0.001	29.27	5.03-170.38	0.000	3.39	1.09-10.59	0.035
Big Box (Yes) × High cul-de-sacs st. % (Bad)	5.58	2.36-13.17	0.000	6.76	1.84-24.81	0.004	24.21	4.23-138.66	0.000	3.50	1.25-9.84	0.035
Big Box (Yes) × low cul-de-sacs st. % (Good)	7.60	2.38-24.21	0.001	6.53	1.69-25.27	0.007	27.34	4.43-168.85	0.000	4.16	1.25-13.90	0.021
Main St. (Yes) × High cul-de-sacs st. % (Bad)	8.58	3.81-19.36	0.000	14.85	4.03-54.67	0.000	49.20	8.71-277.82	0.000	4.37	1.54-12.39	0.006
Main St. (Yes) × low cul-de-sacs st. % (Good)	10.25	4.42-23.79	0.000	18.56	4.92-70.00	0.000	67.12	11.44-393.8	0.000	4.79	1.62-14.16	0.005

Liveable Neighbourhoods Requirements	≥ 60 minutes of walking for transport per week			≥ 60 minutes of walking for recreation per week			≥ 60 minutes of total walking per week			≥ 150 minutes of total walking per week		
	OR	95% CI	<i>p</i> value	OR	95% CI	<i>p</i> value	OR	95% CI	<i>p</i> value	OR	95% CI	<i>p</i> value
Configuration Of Centre 1600m (Main Street/Big Box) × Sidewalk : Road Ratio (High/Low)												
Overall Interaction Term			0.773			0.001			0.000			0.736
No centre × Sidewalk : Road Ratio (Low)*	1.00			1.00			1.00			1.00		
No centre × Sidewalk : Road Ratio (High)	1.25	0.33-4.79	0.745	3.12	1.48-6.58	0.003	6.09	2.71-13.72	0.000	1.20	0.42-3.45	0.737
Big Box (Yes) × Sidewalk : Road Ratio (Low)	4.01	1.21-13.56	0.023	2.25	1.17-4.30	0.015	5.64	2.70-11.78	0.000	1.67	0.84-3.34	0.144
Big Box (Yes) × Sidewalk : Road Ratio (High)	4.47	1.81-11.04	0.001	2.94	1.59-5.41	0.001	7.42	3.91-14.05	0.000	1.34	0.57-3.18	0.505
Main Street (Yes) × Sidewalk : Road Ratio (Low)	6.19	2.45-15.65	0.000	9.45	0.60-147.97	0.110	7.16	1.29-39.68	0.024	1.78	0.85-3.77	0.121
Main Street (Yes) × Sidewalk : Road Ratio (High)	16.23	0.64-131.23	0.091	5.87	3.08-11.22	0.000	12.04	6.06-23.92	0.000	2.54	0.81-7.63	0.110
Public Parkland × Movement Network Requirements												
Footpath : road ratio (High/Low) × Number of Park within the Development (High/Low) [Reference Group = Low footpath : road ratio × low number of parks present]												
Overall Interaction Term			0.700			0.022			0.097			0.232
Number of parks (low) × footpath:road ratio (low)	1.00			1.00			1.00			1.00		
Number of parks (low) × footpath:road ratio (High)	0.97	0.54-1.74	0.915	1.08	0.74-1.57	0.697	0.97	0.65-1.47	0.898	1.22	0.85-1.74	0.279
Number of parks (high) × footpath:road ratio (high)	2.28	1.54-3.39	0.000	2.47	1.86-3.27	0.00	2.30	1.68-3.15	0.000	1.74	1.17-2.57	0.006
Number of parks (high) × footpath:road ratio (low)	1.97	0.91-4.27	0.086	1.23	0.81-1.86	0.392	1.29	0.72-2.31	0.392	1.50	1.33-1.74	0.000
Access to a large/regional park (>4ha) within 2.5km (Yes/No) * footpath to road ratio (high / low) [Reference group = NO access to a regional park within 2.5km × LOW footpath : road ratios]												
Overall Interaction Term			0.040			0.001			0.000			0.070
Park ≥4ha ≤2.5km (no) × footpath:road (high)	0.27	0.10-0.73	0.010	0.35	0.19-0.64	0.001	0.19	0.06-0.23	0.000	0.44	0.22-0.89	0.024
Park ≥4ha ≤2.5km (no) × footpath:road (low)	1.00			1.00			1.00			1.00		
Park ≥4ha ≤2.5km (yes) × footpath:road (high)	2.46	1.40-4.32	0.002	2.04	1.38-3.02	0.000	1.80	1.15-2.80	0.009	1.25	0.85-1.83	0.259
Park ≥4ha ≤2.5km (yes) × footpath:road (low)	2.42	1.47-3.97	0.000	1.36	0.86-2.16	0.195	1.33	0.77-2.29	0.312	1.17	0.68-2.01	0.560

† Adjusted for demographic characteristics (age; gender; education, children ≤18 years and under living at home) and self-selection factors as well as the stage of construction and scale of development; * Reference group; Bold denotes $p < 0.05$; OR = odds ratio; 95%CI = 95% confidence intervals

745 **Figure 1** **The building blocks of a Liveable Neighbourhood: Key policy requirements**
746 **from the community design (CD), movement network (MN), lot layout (LL) and**
747 **public parkland (PP) elements for walking**
748

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